

Use of environmental indices to refine the estimation of multi-year catch projections for specifying annual catch limits (ACLs)

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Background. The reauthorized Magnuson-Stevens Act requires the specification of Annual Catch Limits (ACLs) and accountability measures (AMs) that are triggered if an ACL is exceeded in any year. Conducting assessments annually to estimate ACLs for all 62 stocks assessed by the NEFSC is not an option because there is insufficient personnel (and time) for aging the sampled hardparts (scales, otoliths) and performing the modeling. Therefore, multi-year ACL specifications will have to be made between assessments by projecting catch scenarios into the future. If the stock is estimated to be overfished, then projections are made to provide advice on catch levels that would achieve rebuilding with a specified risk in a time frame not to exceed ten years. Otherwise, if the stock is not overfished, catch levels are estimated that would maximize yield from the resource with a specified risk of not overfishing and not moving towards an overfished state.

The underlying assumptions made in the projections of future catch levels, and in the calculation of reference points to determine stock status, are a key source of uncertainty in providing management advice. The most recent approach for groundfish stocks with age structured assessments (NEFSC 2008) was to perform a yield per recruit (YPR) analysis to calculate an F that corresponded to a spawning potential ratio (SPR) of 40%. The weights at age in the YPR analysis were derived from a recent average, typically the most recent 3 to 5 years. Those same weights at age were used in making the catch projections. Projections also require an assumption about future recruitments. For stocks with age structured assessments, projected recruitment was sampled from an empirical distribution based on a subset of the assessment estimated recruitments, e.g., recruitments that were “observed” when the stock was at low levels were used to create the recruitment distribution for a depleted stock projection.

The approach described above was adopted due to poor or unacceptable fits of stock-recruit relationships. It reflects an acknowledgement that stock parameters are not constant (hence the use of a recent average for weights at age) and that recruitment is not completely random (a “relevant” subset of observations are used). However, a tacit assumption is that recent conditions that have affected weights at age, and conditions that produced the “observed” recruits at given spawner levels, will persist for the length of the projection. If either of these assumptions is violated, then reference points may not be appropriate, projected catches could be biased, acceptable risk levels would be different from what was intended, and ultimately, rebuilding schedules may not be met, as evidenced by recent examples. In 2005, the mean weights at age used in projections to determine a catch quota for haddock on eastern Georges Bank were heavier than what the population attained, which resulted in quotas being too large (Van Eeckhaute and Brodziak, 2006). Georges Bank yellowtail flounder, which is overfished, was supposed to be rebuilt by 2014. It is now estimated that this rebuilding target cannot be met, due to a combination of projected recruitments being higher than what was realized, as well as a change in perceived strength of a recent cohort. New projections to estimate what year

rebuilding can be achieved depend strongly on the period from which recruitments are sampled and the risk tolerance that managers are willing to accept (Legault et al. 2010).

FATE-funded projects in the past have attempted the estimation of recruitment success given an environmental forcing (Mountain et al. (2006), Churchill et al. (2009)), or sought an environmental-biological mechanism to explain recruitment variability (Wuenschel et al. (2009)). Although valuable information was gained, none of this earlier work has been incorporated into either the assessment or the management advice. The goal of this FATE project proposal is to develop environmental indices that can be used as a ‘signpost’ or ‘stoplight’ indicator to gauge the likelihood that assumptions made for catch projections are consistent with realized conditions. This project would represent the first time in our region that auxiliary environmental information was used directly in stock assessment projections to inform management advice.

Approach.

1. Identifying relationships between stock productivity and environmental indices: We propose to examine a variety of environmental indices to determine whether they are able to explain variability in measures of stock productivity. As candidate species, we will select three of the most important commercial groundfish fisheries in the northwest Atlantic: cod, haddock, and yellowtail flounder on Georges Bank. Focusing in one geographic region on three different stocks will provide interesting contrasts in life history, stock status, and population dynamics. While all three stocks have experienced the same environmental conditions, differences in the timing of biological processes (growth and reproduction) relative to environmental events may explain some of the observed differences in productivity. For example, cod have a protracted spawning period across the entire bank that spans the months of October to July, with a peak in March-April. Haddock spawn primarily on the eastern edge of the bank from January through June, with a peak in April. Yellowtail flounder spawning is more concentrated on the western bank, lasting from March to July with a peak in May.

We aim to relate the observed temporal differences in productivity between stocks (as measured by recruitment anomalies and weight at age) to environmental indices. These stocks show some similarity in major trends in productivity, but the strength of signal (and sometimes the direction) is quite variable. This may in part be due to different exploitation histories, but it may also be due to differential exposure and susceptibility to environmental forces.

We will look at multiple environmental indices starting with wind-derived and then circulation-model-derived transport. The potential for these types of environmental processes to influence stock productivity is well documented by existing literature, some of which is contradictory. For example, no relation was found between NAO and Georges Bank wind index and haddock recruitment (Rothschild et al. 2005), nor for an index of interannual wind velocity (Drinkwater et al. 2003). However, Brodziak and O’Brien (2005) found a positive relationship between the NAO forward lagged by 2 years and recruits per spawner for cod, haddock and yellowtail flounder on Georges Bank. More recently, Mountain et al. (2008) proposed a simple wind index for loss of cod and haddock eggs off the bank as a mechanism for recruitment success; greater retention of eggs and larvae on the bank may result in higher recruitment (Lough et al. 1994;

2006). A relationship between wind stress, turbulence, and larval mortality may exist, implying an optimal turbulence for survival based on the theory of predator-prey contact rates (Lough and O'Brien, 2010). In the same vein, spawning earlier in the season to avoid the seasonal increase in the predator wave may lead to higher recruitment (Lapolla and Buckley, 2005; Buckley et al. 2010). For cod, however, year classes following high recruitment years are lower because of density-dependent predation and cannibalism (see Lough, 2010).

Another readily available environmental index to be explored is the North Atlantic Oscillation (NAO) effects on basin to regional circulation and plankton populations since there is a high correlation between the latitude of the Gulf Stream and NAO index about 2 years later (Taylor and Stephens, 1998). In the positive NAO phase, westerly winds intensify and the Gulf Stream shifts north; however, in the negative phase westerly winds diminish and the Gulf Stream shifts south resulting in increased transport of the Labrador Current south along the Scotian Shelf to Gulf of Maine (Greene et al. 2003). Numerical modeling indicated that salinity was the main factor influencing the phytoplankton bloom timing and magnitude in this region (Song et al. 2010). Lower inflow of Scotian Shelf waters with lower salinity also has been associated with increased winter phytoplankton production and zooplankton (Durbin et al. 2003; Pershing et al. 2005), which have effects on the Georges Bank populations (Mountain and Kane (2010)).

Temperature- and primary production-based indices could also be explored. Warmer temperatures promote larval cod and haddock growth at the same time that prey abundance increases to compensate for higher metabolism (Buckley et al. 2006). Greater abundance of the principle larval prey, *Pseudocalanus* spp., is associated with greater growth and presumably better survival (Buckley and Durbin, 2006). Yellowtail flounder year class strength was found to be inversely correlated with water temperature off southern New England (Sissenwine, 1974), although later work found that recruitment variability was the result of a complex interaction between climate and cold pool features in the Middle Atlantic Bight (Sullivan et al. 2005). High haddock recruitment may be correlated with high phytoplankton production in the fall, which Friedland et al. (2009) believe may promote better fecundity and egg quality resulting in better larval survival. High haddock recruitment on the Scotian Shelf has been correlated with early spring bloom leading to more prey for larvae (Platt et al. 2003; Head et al. 2005).

Many of these previous studies are focused on processes acting on eggs, larvae, and recently settled young of the year. Data for these life stages are available from ichthyoplankton surveys that have been conducted since 1977 to monitor the distribution and abundance of eggs and larvae. More intensive process studies were conducted during 1977-78 (MARMAP) (Berrien and Sibunka, 1999; Lough et al. 2006) and 1995-99 (GLOBEC) (Sibunka et al. 2006; Mountain et al. 2008) to estimate loss and retention of egg and larvae, larval growth and survival and factors that could influence year class size at recruitment.

The contribution of these processes to the retention/loss from the bank can be estimated with the Finite Volume Coastal Ocean Model (FVCOM, Chen et al. 2003). The FVCOM is a 3-d time-varying circulation for Georges Bank and the Gulf of Maine. Driven by a global circulation model at the boundaries, an in-house weather model at the surface, and assimilated with observations of temperature and salinity, it provides some of the most realistic flow fields in our region. While there are other models to choose from in our region that are designed for

particular studies, times, and places, we choose to use the FVCOM output given the model authors' commitment to both the Mass Ocean Partnership funded 30 year hindcast project as well as their connection with NOAA's Northeast Regional Association of Coastal Ocean Observing Systems (NERACOOS). Tools have been developed to track particles through these fields in order to investigate the inter-annual variability of larval settlement in preferred regions. For this project, an index can be derived such as the "percentage of numerical particles released in a given spawning ground that are retained within a specified isobath on the southern flank of Georges Bank." Using the improved and more realistic FVCOM circulation model will allow us to better resolve the source, retention and loss of eggs and larvae from specific spawning sites over the time series and the variable mixing between stocks during their early life history.

In addition to the full scale numerical FVCOM hindcast, we plan to first experiment as to whether a simpler index, based on a longer time series of data, can reproduce the same temporal trend. The National Center for Environmental Prediction's wind product exists for multiple decades at multiple locations around the study area. Particular components of the wind can be tested as a forcing for recruitment success and these indices can then be compared to the primary FVCOM-derived index.

2. Evaluating performance of stock projections with and without environmental indices:

We plan to partition the time series of stock assessment and environmental data into 'training' and 'validation' sets. The training set will be used to examine relationships between stock dynamics and environmental indices, while the 'validation' sets will evaluate whether projections from the training data sets have greater accuracy and precision when environmental indices are included than when the simple 'status quo' approach is taken. As an example, if the environmental index and the stock assessment overlap for 25 years, then the first 20 years of temporal overlap will be used to develop relationships with environmental indices. The stock assessment at the end of year 20 would be projected 5 years (the last 5 years of temporal overlap) with two different approaches:

- i) Status quo: use a recent 5 year average for weights at age, and sample from recruitments that correspond to recently observed levels of SSB; project 5 years ahead
- ii) Status quo with environmental updating: take the status-quo projections (i), and apply control rule to update the projections annually in each of the next 5 years based on the realized value for environmental indices

An example control rule for (ii) would be to modify the recruitments that were used for projection if after one year, realized environmental indices fell in a range where low recruitment is typically observed.

The two different projection methods will be evaluated by comparing the projected median SSB at each year of the projection to the "true" outcome from the assessment (since the assessment has already been conducted for those years, the "true" outcome is what the assessment estimated for those years).

For this exercise, we will assume the ‘true’ selectivity (as estimated from the full assessment time series) for both projection methods. This will allow us to focus on differences in the two projection methods, and determine whether we can reduce uncertainty by updating the distribution of recruitments from which we sample. To address the robustness of environmental relationships that we identify, we will apply cross-validation techniques. This can be done by sampling temporally (only use data from the 1970s and 1980s to estimate a relationship, and then test it for data on data from the 1990s), or randomly, and will address the concern whether relationships that are identified break down when new observations are added.

Plan of work. Work is expected to require two years of post-doc time, with each step of the approach requiring about a year. In Year 1, time would be spent familiarizing the post-doc with oceanographic data bases and stock assessment data, developing environmental indices and examining the relationship between those indices and measures of stock productivity. In Year 2, the assessment/projection training and validation step would be explored, and the robustness of identified relationships with environmental indices would be tested with cross validation techniques. Results of these studies will be submitted for publication in peer reviewed journals.

Benefits. Assumptions are made when performing projections to determine the distribution of future catches. When those assumptions aren’t met, stock status, rebuilding plans, and future catch quotas can be jeopardized. If an environmental forcing agent plays an important role in determining recruitment success, or if the strength of a seasonal bloom affects mean weights at age, then those environmental drivers should be monitored during the projection time horizon so that catch advice can be revised, if needed. This project does not propose to forecast environmental indices, rather it proposes to use realized values of those indices in the projection period between assessments to reduce uncertainty in the distribution of future catches. Reducing uncertainty in the projections could be reflected in the size of buffers that are recommended between an optimal and an allowable catch level. The results of this project will be communicated to managers and members of the Science and Statistical Committee (who ultimately recommend catch levels and buffers to the Fishery Management Councils).

Results from past FATE funding: **FY09** -Wuenschel, Friedland, **Brooks**, Sutherland, McBride; Evaluating the influence of the fall phytoplankton bloom on the energy available for growth and reproduction, and subsequent recruitment of Georges Bank haddock: Measured 5,772 increments from archived 1,731 otolith sections collected over an eleven year period to determine the effect of the environment on year-specific growth of pre-reproductive and reproductive fish of both sexes. Results offer several lines of supporting evidence for an effect of the fall bloom on the productivity of Georges Bank haddock *via* parental condition. **FY08** –Churchill, Runge, **Manning, O’Brien**; Predictors for Larval Transport Success and Recruitment for Cod in the Gulf of Maine: FVCOM velocity fields were used to predict larval transport and settlement of juvenile cod in the Gulf of Maine. Results indicated that better recruitment is obtained with a mean downwelling favorable wind during May. **FY06**- Mountain, **Manning, O’Brien**, Brodziak; Wind-Driven Transport Indices for Cod and Haddock Recruitment on Georges Bank: A wind index was derived to understand recruitment success of cod and haddock on Georges Bank, however the wind index values did not compare well with the recruitment values derived through a VPA analysis. This was interpreted as being due to other contemporaneous forcing functions (changes in salinity that drove changes in zooplankton community structure).

References

- Beggs, G.A., Hare, J.A., Sheehan, D.D. 1999. The role of life history parameters as indicators of stock structure. *Fish. Res.* 43:141-163.
- Berrien, P., Sibunka, J. 1999. Distribution patterns of fish eggs in the U.S. northeast continental shelf ecosystem, 1977-1987. NOAA Tech. Memo. NMFS-NE 145.
- Brander, K. 2010. Impacts of climate change on fisheries. *J. Mar. Sys.* 79:389-402.
- Brodziak, J. and L. O'Brien. 2005. Do environmental factors affect recruits per spawner anomalies of New England groundfish? *ICES J. Mar. Sci.* 62:1394-1407.
- Churchill, J.C., J. Runge, and C. Chen, 2010. Processes controlling retention of spring-spawned Atlantic cod (*Gadus morhua*) in the Western Gulf of Maine and their relationship to an index of recruitment success. Submitted to *Fisheries Oceanography*
- Buckley, L.F., and E. G. Durbin. 2006. Seasonal and inter-annual trends in the zooplankton prey and growth rate of Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) larvae on Georges Bank. *Deep-Sea Res. II* 53: 2758-2770.
- Buckley, L. J., E. M. Caldarone, R. G. Lough, and J. M. St. Onge-Burns. 2006. Ontogenetic and seasonal trends in recent growth rates of Atlantic cod and haddock larvae on Georges Bank: effects of photoperiod and temperature. *Mar. Ecol. Prog. Ser.* 325:205-226.
- Buckley, L. J., R. G. Lough, and D. Mountain. 2010. Seasonal trends in mortality and growth of cod and haddock larvae result in an optimal window for survival. *Mar. Ecol. Prog. Ser.* 405:57-69.
- Chen, C., Liu, H., Beardsley, R.C. 2003. An unstructured, finite-volume, three-dimensional, primitive equation ocean model: application to coastal ocean and estuaries. *J. Atmos. Oceanic Tech.* 20:159-186.
- Drinkwater, K.F., Belgrano, A., Borja, A., Conversi, A., Edwards, M., Greene, C.H., Ottersen, G., Pershing, A.J., Walker, H. 2003. The response of marine ecosystems to climate variability associated with the North Atlantic Oscillation. *Geophys. Monogr.* 134, AGU 10.1029/134GM10.
- Fogarty, M., Incze, L., Hayhoe, K., Mountain, D., Manning, J. 2008. Potential climate change impacts on Atlantic cod (*Gadus morhua*) off the northeastern USA. *Mitig. Adap. Strat. Glob. Change* 13:453-466.
- Friedland, K. D., J. A. Hare, G. B. Wood, L. A. Col, L. J. Buckley, D. G. Mountain, J. Kane, J. Brodziak, R. G. Lough, and C. H. Pilskaln. 2008. Does the fall phytoplankton bloom control recruitment of Georges Bank Haddock, *Melanogrammus aeglefinus*, through parental condition? *Can. J. Fish. Aquat. Sci.*, 65:1076-1086.
- Greene, C.H., Pershing, A.J., Conversi, A., Planque, B., Hannah, C., Sameoto, D., Head, E., Smith, P.C., Reid, P.C., Jossi, J. Mountain, D., Benfield, M.C., Wiebe, P.H., Durbin,

- E. 2003. Trans-Atlantic responses of *Calanus finmarchicus* populations to basin-scale forcing associated with the North Atlantic Oscillation. *Prog. Oceanogr.* 58:301-312.
- Head, E. J. H., D. Brickman, and L. R. Harris. 2005. An exceptional haddock year class and unusual environmental conditions on the Scotian Shelf in 1999. *J. Plankton Res.* 27:597-602.
- Heath, M. R., and R. G. Lough. 2007. A synthesis of large-scale patterns in the planktonic prey of larval and juvenile cod (*Gadus morhua*). *Fish. Oceanogr.* 16:169-185.
- Hurrell, J.W., Kushnir, Y., Ottersen, G., Visbeck, G. (eds). 2003. The North Atlantic Oscillation: climatic significance and environmental impact. *Geophys. Monograph* 134, Am. Geophys. Union, Washington, D.C.
- Lapolla A., Buckley, L.J. 2005. Hatch-date distributions of young-of-the-year haddock (*Melanogrammus aeglefinus*) in the Gulf of Maine/Georges Bank region: implications for recruitment. *Mar. Ecol. Prog. Ser.* 290:239-249.
- Legault, C.M., L. Alade, and H.H. Stone. 2010. Stock assessment of Georges Bank yellowtail flounder for 2010. Transboundary Resource Assessment Committee Reference Document 2010/06. 97 p.
- Lough R.G., Mountain, D.G. 1996. Effect of small-scale turbulence on feeding rates of larval cod and haddock in stratified water on Georges Bank. *Deep-Sea Res. II* 43:1745-1772.
- Lough, R.G., C. G. Hannah, P. Berrien, D. Brickman, J. W. Loder, J. A. Quinlan. 2006. Spawning pattern variability and its effect on retention, larval growth and recruitment in Georges Bank cod and haddock. *Mar. Ecol. Prog. Ser.* 310:193-212.
- Lough, R.G., O'Brien, L., Buckley, L.J. 2008. Differential egg mortality of Georges Bank cod and haddock inferred from two independent estimates of seasonal egg production. *J. Northw. Atl. Fish. Sci.* 41:119-128.
- Lough, R.G. 2010. Juvenile cod (*Gadus morhua*) mortality and the importance of bottom sediment type to recruitment on Georges Bank. *Fish. Oceanogr.* 19:159-181.
- Lough, R.G., O'Brien, L. 2010. Stage-specific recruitment models of Atlantic cod and haddock on Georges Bank. *Fish. Bull.*(submitted August)
- Mountain, D.G., J. Manning, L.O'Brien, and J. Brodziak, 2006. Wind-driven Transport Indices for Cod and Haddock Recruitment on Georges Bank.
[http://fate.nmfs.noaa.gov/proposal/Mountain annual rpt.pdf](http://fate.nmfs.noaa.gov/proposal/Mountain%20annual%20rpt.pdf)
- Mountain, D., Green, J., Sibunka, J., Johnson, D. 2008. Growth and mortality of Atlantic cod *Gadus morhua* and haddock *Melanogrammus aeglefinus* eggs and larvae on Georges Bank, 1995 to 1999. *Mar. Ecol. Prog. Ser.* 353:225-242.

Mountain, D. G., Kane, J. 2010. Major changes in the Georges Bank ecosystem, 1980s to the 1990s. Mar. Ecol. Prog. Ser. 398:81-91.

Northeast Fisheries Science Center. 2008. Assessment of 19 Northeast Groundfish Stocks through 2007: Report of the 3rd Groundfish Assessment Review Meeting (GARM III), Northeast Fisheries Science Center, Woods Hole, Massachusetts, August 4-8, 2008. US Dep Commer, NOAA Fisheries, Northeast Fish Sci Cent Ref Doc. 08-15; 884 p + xvii.

Platt, T., Fuentes-Yaco, C., Frank, K.T. 2003. Spring algal bloom and larval fish survival. Nature (London). 423:398-399.

Pershing, J.A., Greene, C.H., Jossi, J.W., O'Brien, L., Brodziak, J.K.T., Bailey, B.A. 2005. Interdecadal variability in the Gulf of Maine zooplankton community, with potential impacts on fish recruitment. ICES J. Mar. Sci. 62:1511-1523.

Rothschild, B. J., Chen, C., Lough, R.G. 2005. Managing fish stocks under climate uncertainty. ICES J. Mar. Sci. 62:1531-1541.

Sibunka J.D., Johnson, D.L., Berrien, P.L. 2007. Distribution and abundance of fish eggs collected during the GLOBEC broad-scale Georges Bank surveys, 1995–1999. NOAA Tech. Memo. NMFS-NE 199.

Sissenwine, M.P. 1974. Variability in recruitment and equilibrium catch of the southern New England yellowtail flounder fishery. J. Cons. Int. Explor. Mer 36:15-26.

Song, H., Ji, R., Stock, C., Wang, Z. 2010. Phenology of phytoplankton blooms in the Nova Scotia Shelf-Gulf of Maine region: remote sensing and modeling analysis. J. Plankton Res. 32:1485-1499.

Sullivan, M.C., R.K. Cowen, and B.P. Steves. 2005. Evidence for atmosphere-ocean forcing of yellowtail flounder (*Limanda ferruginea*) recruitment in the Middle Atlantic Bight. Fisheries Oceanography. 14: 386-399.

Taylor, A.H., Stephens, J.A. 1998. The North Atlantic Oscillation and the latitude of the Gulf Stream. Tellus 50A: 134-142.

Van Eeckhaute, L. and J. Brodziak. 2006. Assessment of haddock on eastern Georges Bank. TRAC Ref. Doc. 2006/06: 76 p

Wuenschel, M., K. Friedland, E. Brooks, S. Sutherland, R. McBride, 2009. Evaluating the influence of the fall phytoplankton bloom on the energy available for growth and reproduction, and subsequent recruitment of Georges Bank haddock. <http://fate.nmfs.noaa.gov/report/09-11%20Wuenschel%20report%202010.pdf>

